DOE/BC/15127-5

An Advanced Fracture Characterization and Well Path Navigation System for Effective Re-Development and Enhancement of Ultimate Recovery from the Complex Monterey Reservoir of South Ellwood Field, Offshore California

Quarterly Technical Progress Report

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Progress Report July 1 - September 30, 2001

Disclaimer

Abstract

Venoco Inc, intends to re-develop the Monterey Formation, a Class III basin reservoir, at South Ellwood Field, Offshore Santa Barbara, California.

Well productivity in this field varies significantly. Cumulative Monterey production for individual wells has ranged from 260 STB to 8,700,000 STB. Productivity is primarily affected by how well the well path connects with the local fracture system and the degree of aquifer support. Cumulative oil recovery to date is a small percentage of the original oil in place. To embark upon successful re-development and to optimize reservoir management, Venoco intends to investigate, map and characterize field fracture patterns and the reservoir conduit system. State of the art borehole imaging technologies including FMI, dipole sonic and cross-well seismic, interference tests and production logs will be employed to characterize fractures and micro faults. These data along with the existing database will be used for construction of a novel geologic model of the fracture network. Development of an innovative fracture network reservoir simulator is proposed to monitor and manage the aquifer's role in pressure maintenance and water production. The new fracture simulation model will be used for both planning optimal paths for new wells and improving ultimate recovery.

In the second phase of this project, the model will be used for the design of a pilot program for downhole water re-injection into the aquifer simultaneously with oil production. Downhole water separation units attached to electric submersible pumps will be used to minimize surface fluid handling thereby improving recoveries per well and field economics while maintaining aquifer support.

In cooperation with the DOE, results of the field studies as well as the new models developed and the fracture database will be shared with other operators.

Numerous fields producing from the Monterey and analogous fractured reservoirs both onshore and offshore will benefit from the methodologies developed in this project.

This report presents a summary of all technical work conducted during the fifth quarter of Budget Period I.

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Introduction

The Field Demonstration site for this Class III (basin clastic) Program Proposal is the South Ellwood Field located offshore California. The Monterey Formation is the main producing unit in the South Ellwood Field and consists of fractured chert, porcelanite, dolomite, and siliceous limestone interbedded with organic mudstone. This reservoir has an average thickness of 1,000 feet, and lies at subsea depths of approximately -3,500’ to -5,000’.

Venoco and USC jointly submitted an application to conduct a DOE co-operative investigation of the Monterey formation at South Ellwood in June 2000. The DOE granted this application in July 2000.

Executive Summary

Venoco and USC prepared a proposal for a DOE sponsored joint investigation of the fractured Monterey formation. It was agreed that Venoco would construct the geologic model for the field and gather new reservoir data as appropriate. USC would then develop a simulation model that would be used to optimize future hydrocarbon recovery. Joint Venoco-USC teams were established to manage the flow of data and insure that Venoco and USC activities remained synchronized. A co-operative agreement was signed with the DOE on July 31, 2000.

The migration of the South Ellwood database to the Web site is now complete. The database is updated with new production data on a monthly basis. An automated curve generator feature has been added so that users can display the latest production data in real time. This database will be made available to the general public through a link on the PTTC web site.

The fracture pipeline network model algorithm has been formulated in 3-D. This new simulation model is being coded and will be tested against a conventional dual porosity model available from CMG. The CMG package was purchased an installed at sites at USC and Venoco. A CMG model is being put together for South Ellwood using all the data in the Web database. The pipeline network model will be benchmarked against the CMG model. Should it prove useful for South Ellwood, CMG has committed itself to making the pipeline network model available to users as a simulation option within CMG. The algorithm for the pipeline network model was presented at the annual fall meeting of the SPE.

Task I-Database

While updating and adding more information to the web site, we included the organization chart and brief description of the project for potential users. Also we developed an automated curve generator to exhibit diagnostic data.

Fig. 1 Main Page of the Web site for the Project

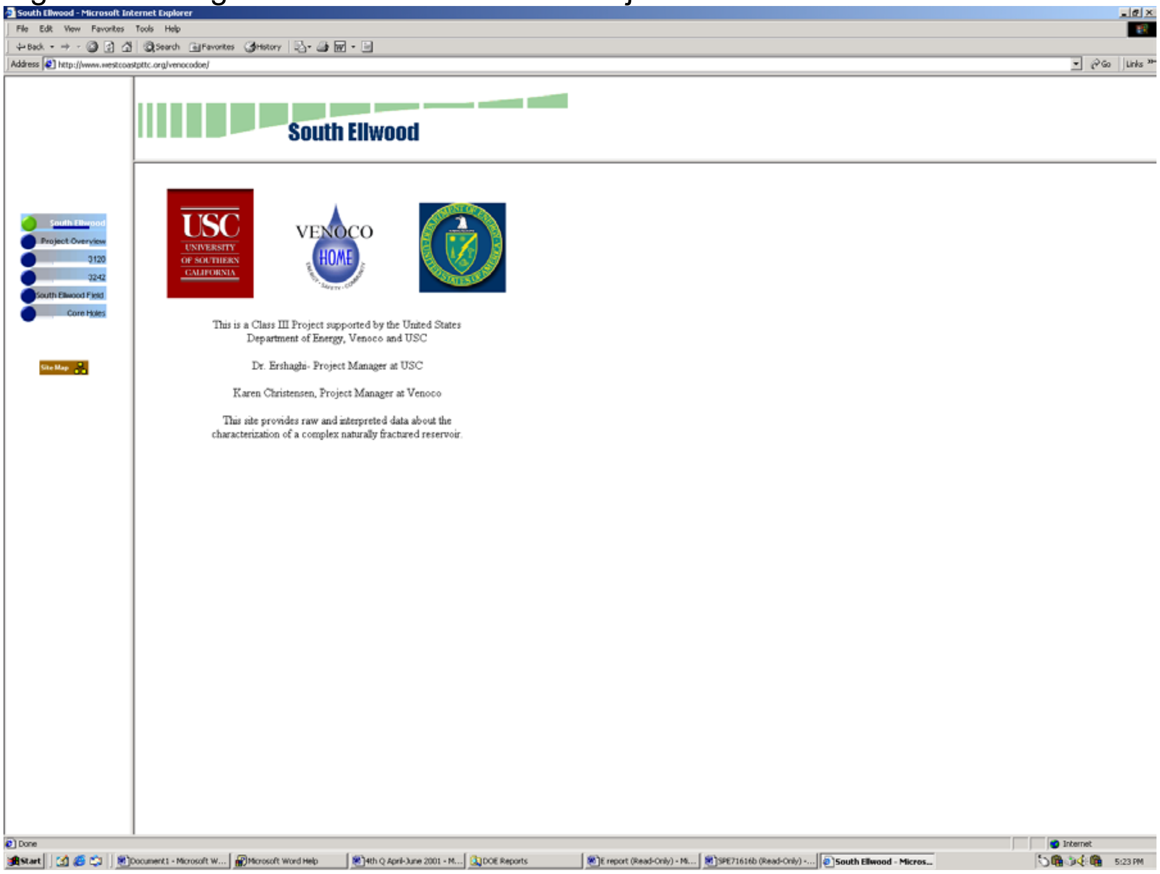


Fig. 2 Menu of Available Data

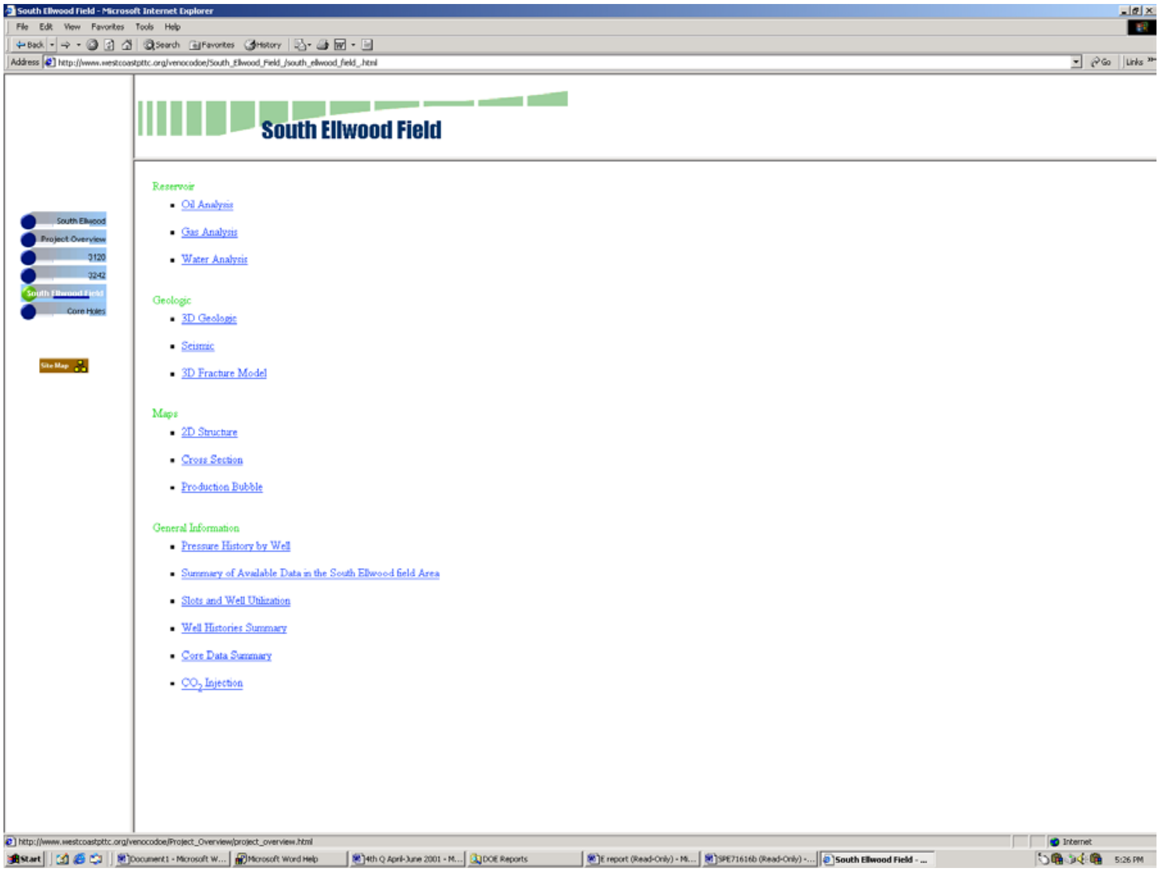


Fig. 3 List of Diagnostic Plots

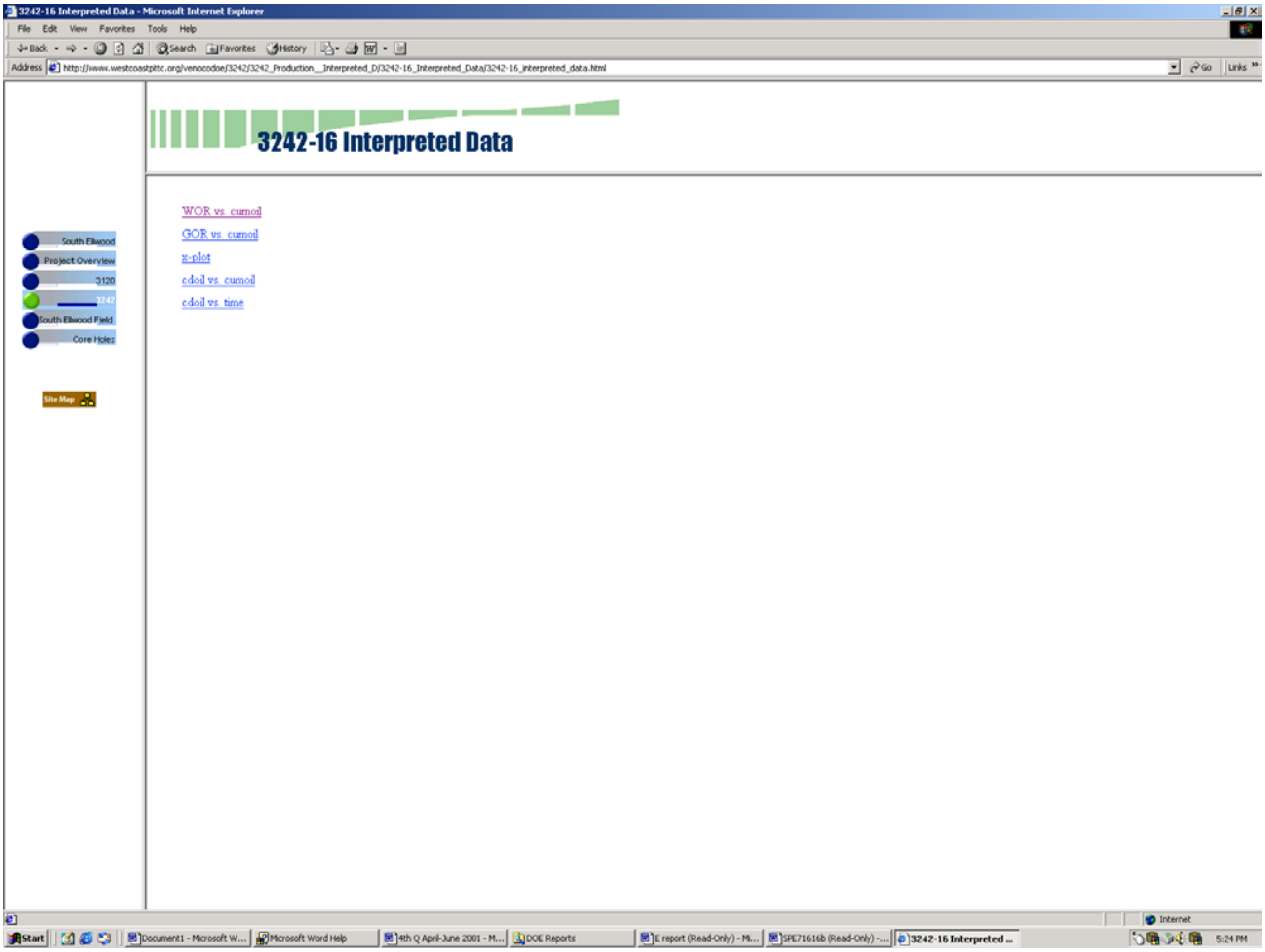


Fig 4 Sample Graph Generator

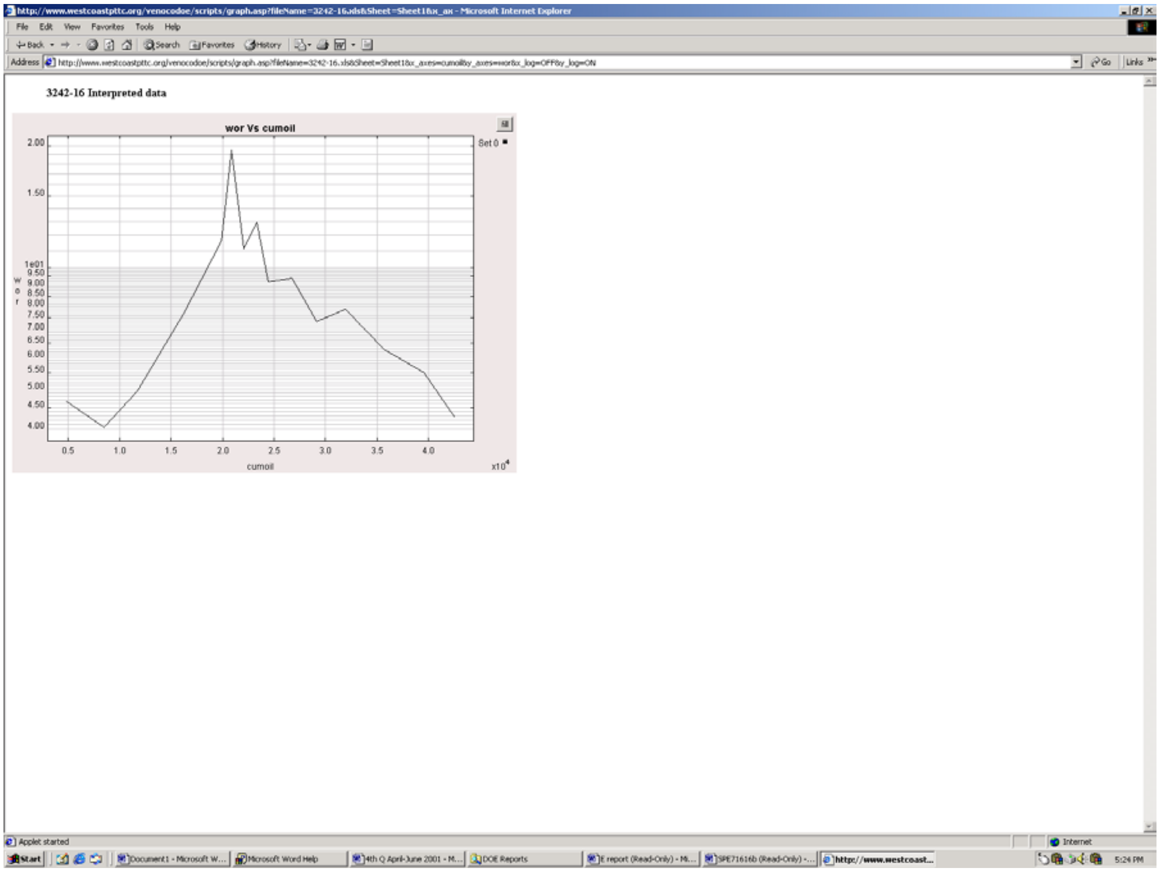
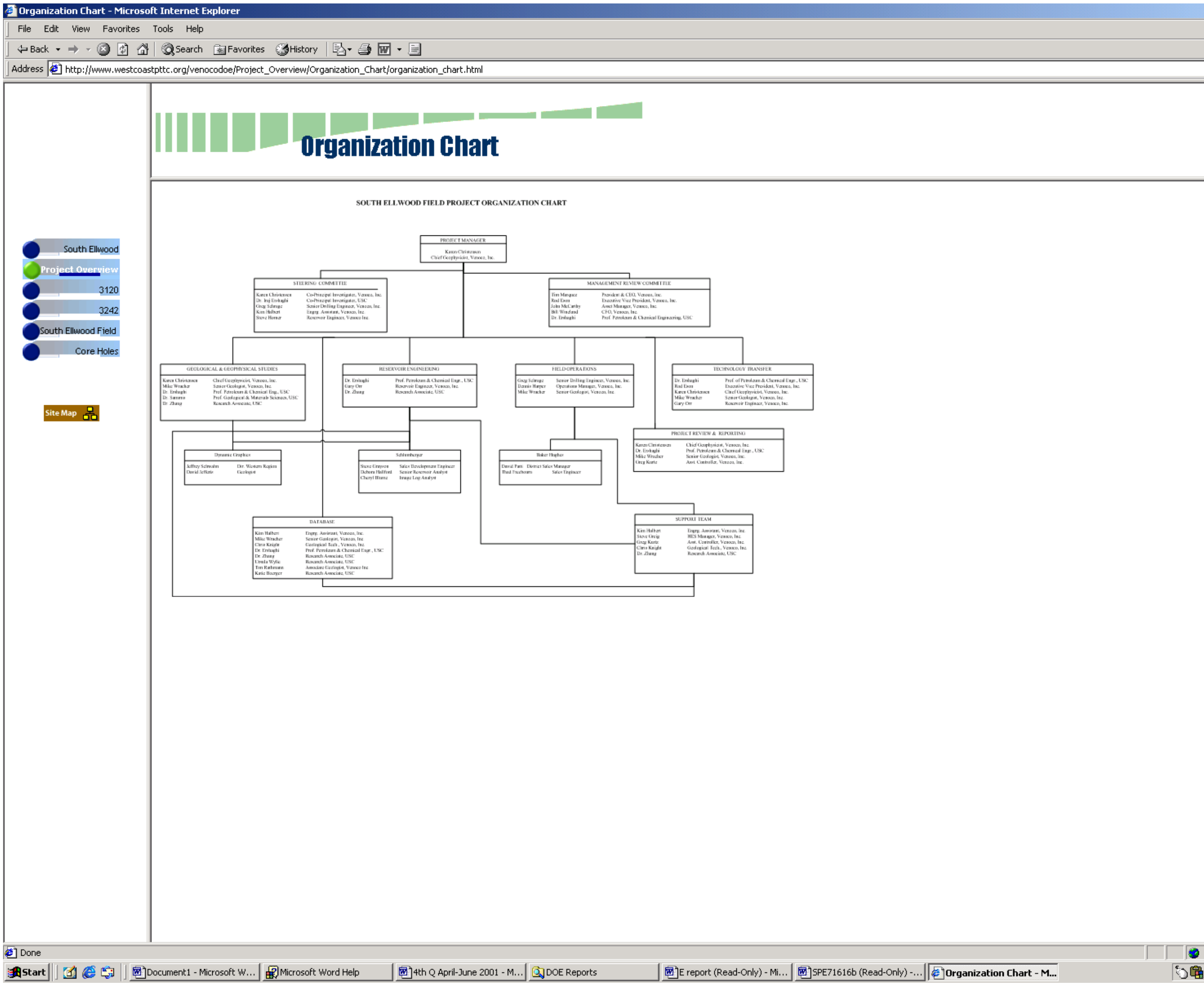


Fig. 5 Organization chart



Task II: New Data

Conducted a second Water flow log in Sockeye E-4 long string to detect the source of water entry into the short string Monterey perforations. Determined that water was moving outside the casing from the Base of the Monterey and entering the bottom set of perforations. This provides a second water shut-off candidate at Sockeye field.

Task III: Basic Reservoir Studies

Schlumberger processed dipmeter data from two vertical wells 208-102 and 309-8. Minimum stress direction is SE in 208-102 and SSW in 309-8. There is a good correlation between the fault orientation in the area of these two wells and the maximum stress orientation as defined from the borehole breakouts. Constructed and exported the geologic model for reservoir simulation.

Simulation Study

- Finalized and signed contract with Computer Modeling Group (CMG), and established two dedicated CMG simulator stations in USC (Los Angeles) and Venoco, Inc. (Carpinteria).
- Performed detailed review of simulator general dataset structure and relevant sections in IMEX (black oil simulator) manual, as the starting steps for a full-field simulation of South Ellwood Monterey formation.
- Established South Ellwood simulation task flow chart and tentative time schedule.
- Reviewed recent fluid entry surveys performed by Schlumberger to gain a better understanding of water-oil-contact (WOC).
- Prepared monthly, quarterly and yearly production rate datasets based on IMEX required well data format.
- Initiated a review of available structural and stratigraphic information in the EarthVision model exported to CMG format.

Water Influx Calculation

X-Plot technique: The technique of X-Plot was applied to the production dataset to calculate the current amount of water influx based on assumed values of oil formation volume factor.

Total water influx based on Bo=1.15 : 23MMBBL
Total water influx based on Bo=1.1 : 22MMBBL

The Pipe Network Model (PNM)

Returning to equations (5) and (6) of report 3, we can develop a semi-implicit finite difference formulation for implementing the flow equations, where only the first term in (5) and right hand side terms in (5) and (6) need to be considered. For the flow rate between junction “l” and “j”, the discretization can be obtained by

$$Q_{\alpha l,j} = -\frac{\beta A_{l,j}\, k_{l,j}\, k^*_{r\alpha p}}{(\mu_\alpha B_\alpha)^*\, s_{l,j}}\left[(p_{\alpha pl} - p_{\alpha pj}) - \gamma^* \Delta Z_{l,j}\right] \qquad (7)$$

where strong nonlinear term, $k^*_{r\alpha p}$, is calculated using upstream method, i.e., depending on the flow rate direction between “l” and “j”, weak nonlinear terms μ_α, B_α, γ_α are obtained using simple average approach, $\Delta Z_{l,j} = Z_l - Z_j$, is the depth difference between two junctions, and $s_{j,l}$ is the length (only take absolute value) of the pipe between junction “l” and “j”. This discretization ensures the positive value of the flow rate when flow enters the junction “l”, and the negative value when fluid flows out. The right hand side terms in (5) and (6) can be obtained same as those in literature.

$$\begin{aligned}\frac{V_l}{5.615}\frac{\partial}{\partial t}\left(\frac{\phi_\lambda S_{\alpha\lambda}}{B_\alpha}\right) &= \frac{V_l \phi_\lambda}{5.615\, B_\alpha}\frac{\partial S_{\alpha\lambda}}{\partial t} \\ &+ \frac{V_l \phi_\lambda S_{\alpha\lambda}}{5.615\, B_\alpha}\left(-\frac{1}{B_\alpha}\frac{\partial B_\alpha}{\partial p} + \frac{1}{\phi_\lambda}\frac{\partial \phi_\lambda}{\partial p}\right)\end{aligned} \qquad (8)$$

In the above equations (7) and (8), λ=p or m, represent equations for pipe and matrix, respectively.
Using (7) and (8) in Eq. (5) and (6), the finite difference equations read

$$\begin{aligned}&\sum_{j=1}^{M_l}\Pi_{\alpha l,j}\, p_{\alpha pj} - \left(\sum_{j=1}^{M_l}\Pi_{\alpha l,j} + V_l T_{\alpha m}\right) p_{\alpha pl} + V_l T_{\alpha m}\, p_{\alpha ml} + \sum_{j=1}^{M_l} G_{\alpha l,j} \\ &+ N_{\alpha l} = \frac{V_l \phi_p}{5.615\, B_\alpha \Delta t}\left[\Delta_t S_{\alpha p} + S_{\alpha p}(c_\alpha + c_{\phi p})\left(p^{n+1}_{\alpha pl} - p^{n}_{\alpha pl}\right)\right]\end{aligned} \qquad (9)$$

$$\begin{aligned}V_l T_{\alpha m}(p_{\alpha ml} - p_{\alpha pl}) &= \frac{V_l \phi_m}{5.615\, B_\alpha \Delta t}\Delta_t S_{\alpha m} \\ &+ \frac{V_l \phi_m}{5.615\, B_\alpha \Delta t} S_{\alpha m}(c_\alpha + c_{\phi m})\left(p^{n+1}_{\alpha ml} - p^{n}_{\alpha ml}\right)\end{aligned} \qquad (10)$$

where

$$\Pi_{\alpha l,j} = \frac{\beta A_{l,j}\, k_{l,j}\, k^*_{r\alpha p}}{(\mu_\alpha B_\alpha)^*\, s_{l,j}}$$

$$G_{\alpha l,j} = \Pi_{\alpha l,j}\, g_{\alpha l,j}$$

$$g_{\alpha l,j} = \gamma^{*}_{l,j}\, \Delta Z_{l,j}$$

$$\Delta_t S_{\alpha p} = S^{n+1}_{\alpha p} - S^{n}_{\alpha p}$$

$$c_{\alpha} = -\frac{1}{B_{\alpha}} \frac{\partial B_{\alpha}}{\partial p}$$

$$c_{\phi\lambda} = \frac{1}{\phi_{\lambda}} \frac{\partial \phi_{\lambda}}{\partial p}$$

Upon making the Taylor's expansion of the strong nonlinear parameters, $T_{\alpha m}$ and $\Pi_{\alpha p}$, and only keeping the first two terms, the semi-implicit scheme can be obtained for oil phase in pipes:

$$\begin{aligned}
&\sum_{j=1}^{M_j} \Pi^{n}_{ol,j}\, p^{n+1}_{opj} - \left[\sum_{j=1}^{M_j} \Pi^{n}_{ol,j} + V_l T^{n}_{om} + \frac{V_l \phi_p S_{op}}{5.615 B_o \Delta t} \left(c_o + c_{\phi p} \right) \right] p^{n+1}_{opl} \\
&+ \left[\sum_{j=1}^{M_j} \frac{\partial \Pi^{n}_{ol,j}}{\partial S_{wp}} p^{n}_{opj} - \left(\sum_{j=1}^{M_j} \frac{\partial \Pi^{n}_{ol,j}}{\partial S_{wp}} \right) p^{n}_{opl} + \sum_{j=1}^{M_j} \frac{\partial \Pi^{n}_{ol,j}}{\partial S_{wp}} g_{opl,j} + \frac{V_l \phi_p}{5.615 B_o \Delta t} \right] \Delta_t S_{wp} \\
&+ V_l \frac{\partial T^{n}_{om}}{\partial S_{wm}} \left(p^{n}_{oml} - p^{n}_{opl} \right) \Delta_t S_{wm} + V_l T^{n}_{om} p^{n+1}_{oml} \\
&+ N_{ol} = -\sum_{j=1}^{M_j} \Pi^{n}_{ol,j}\, g_{opl,j} - \frac{V_l \phi_p S_{op}}{5.615 B_o \Delta t} \left(c_o + c_{\phi p} \right) p^{n}_{oml}
\end{aligned} \tag{11}$$

water phase in pipes:

$$
\begin{aligned}
&\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}p_{opj}^{n+1}-\left[\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}+V_l T_{wm}^{n}+\frac{V_l\phi_p S_{wp}}{5.615B_w\Delta t}\left(c_w+c_{\phi p}\right)\right]p_{opl}^{n+1}\\
&+\left[\sum_{j=1}^{M_j}\frac{\partial\Pi_{wl,j}^{n}}{\partial S_{wp}}p_{wpj}^{n}-\left(\sum_{j=1}^{M_j}\frac{\partial\Pi_{wl,j}^{n}}{\partial S_{wp}}\right)p_{wpl}^{n}+\sum_{j=1}^{M_j}\frac{\partial\Pi_{wl,j}^{n}}{\partial S_{wp}}g_{wpl,j}-\frac{V_l\phi_p}{5.615B_w\Delta t}\right]\Delta_t S_{wp}\\
&+\left\{\left[\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}+V_l T_{wm}^{n}+\frac{V_l\phi_p S_{wp}}{5.615B_w\Delta t}\left(c_w+c_{\phi p}\right)\right]\frac{\partial p_{cp}^{n}}{\partial S_{wp}}-\sum_{j=1}^{M_j}\frac{\partial p_{cp}^{n}}{\partial S_{wp}}\Pi_{wl,j}^{n}\right\}\Delta_t S_{wp}\\
&+V_l\frac{\partial T_{wm}^{n}}{\partial S_{wm}}\left(p_{wml}^{n}-p_{wpl}^{n}\right)\Delta_t S_{wm}+V_l T_{wm}^{n}p_{wml}^{n+1}+N_{wl}=-\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}g_{wpl,j}\\
&-\frac{V_l\phi_p S_{wp}}{5.615B_w\Delta t}\left(c_w+c_{\phi p}\right)p_{wml}^{n}+\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}p_{cpj}^{n}\\
&-\left[\sum_{j=1}^{M_j}\Pi_{wl,j}^{n}+V_l T_{wm}^{n}+\frac{V_l\phi_p S_{wp}}{5.615B_w\Delta t}\left(c_w+c_{\phi p}\right)\right]p_{cpl}^{n}
\end{aligned}
\qquad (12)
$$

oil phase in matrix:

$$
\begin{aligned}
&T_{om}^{n}p_{opl}^{n+1}-\left[T_{om}^{n}+\frac{\phi_m S_{om}}{5.615B_o\Delta t}\left(c_o+c_{\phi m}\right)\right]p_{oml}^{n+1}\\
&+\left[\frac{\phi_m}{5.615B_o\Delta t}+\frac{\partial T_{om}^{n}}{\partial S_{wm}}\left(p_{opl}^{n}-p_{oml}^{n}\right)\right]\Delta_t S_{wm}\\
&=-\frac{\phi_m S_{om}}{5.615B_o\Delta t}\left(c_o+c_{\phi m}\right)p_{oml}^{n}
\end{aligned}
\qquad (13)
$$

and water phase in matrix:

$$
\begin{aligned}
&T_{wm}^{n}p_{wpl}^{n+1}-\left[T_{wm}^{n}+\frac{\phi_m S_{wm}}{5.615B_w\Delta t}\left(c_w+c_{\phi m}\right)\right]p_{oml}^{n+1}\\
&+\left[\frac{\partial T_{wm}^{n}}{\partial S_{wm}}\left(p_{wpl}^{n}-p_{wml}^{n}\right)-\frac{\phi_m}{5.615B_w\Delta t}\right]\Delta_t S_{wm}\\
&+\left[T_{wm}^{n}+\frac{\phi_m S_{wm}}{5.615B_w\Delta t}\left(c_w+c_{\phi m}\right)\right]\frac{\partial p_{cm}^{n}}{\partial S_{wm}}\Delta_t S_{wm}\\
&=-\frac{\phi_m S_{wm}}{5.615B_w\Delta t}\left(c_w+c_{\phi m}\right)p_{wml}^{n}\\
&-\left[T_{wm}^{n}+\frac{\phi_m S_{wm}}{5.615B_w\Delta t}\left(c_w+c_{\phi m}\right)\right]p_{cm}^{n}
\end{aligned}
\qquad (14)
$$

The coding of this algorithm for a 3-D simulation model is underway. The progress to date was reported in an SPE paper presented at the annual fall meeting of the SPE in October.

Task IV--Stimulation

None

Task V- Project Management

Project review meetings were held on a monthly basis in Santa Barbara. Progress reports from various individuals were reviewed. Individuals working on the project during this quarter included:

Database:
Katie Boerger (USC), Ursula Wiley (USC), Kim Halbert (Venoco) and Tim Rathman (Venoco), Chris Knight (Venoco), I. Ershaghi (USC), A. Patel (USC)

Reservoir Studies:
Ershaghi (USC), Lang Zhang (USC), A. Zahedi (USC), Ursula Wiley (USC), Juan Angiano (USC), Anthony Taglieri (USC), Steve Horner (Venoco)

Geological Modeling
Mike Wracher (Venoco), Karen Christensen (Venoco)

Geophysical Modeling
Karen Christensen (Venoco)

Project Management:
Karen Christensen (Venoco) and I. Ershaghi (USC)

Task VI: Technology Transfer

September 28, 2001
Presented South Ellwood geologic and fracture studies at a Santa Barbara City College Geoseminar (Karen Christensen, Venoco)

October 2, 2001
An Integrated Pipe Network Model for Simulation of Highly Fractured Reservoirs
SPE 71616 Presented at the SPE Fall Meeting in New Orleans.
Lang Zhan, SPE and Iraj Ershaghi, SPE, University of Southern California

Conclusions

The algorithm for the pipeline network model has been developed. It compares very favorably to a conventional dual porosity model in terms of computing hardware required to run large models. It should prove very useful for large simulation models of complex fractured reservoirs where dual porosity models have been shown to be too computationally intensive to be practical.